ASSESSMENT OF HYBRID ATTACHED GROWTH MEMBRANE BIOREACTOR SYSTEM FOR DOMESTIC WASTEWATER TREATMENT

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This thesis is submitted as fulfilment of the
requirements for the award of the degree of
Master of Engineering (Chemical)

Faculty of Chemical and Energy Engineering
Universiti Teknologi Malaysia

NOVEMBER 2016

Dedicated to my beloved family and all my friends

from the bottom of my heart who have guided and inspired me throughout

my journey of education.

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I would like to extend my heartfelt gratitude to my supervisor, Associate Prof Dr Zainura Zainon Noor who gave me the opportunity to complete my Master project under her supervision. She guided me patiently through the dissertation process, never accepting less than my best efforts.

Besides, I would like to express my gratitude and appreciation to her previous PhD students Dr Noor Sabrina Mutamim and Dr Adhi Yuniarto and also her Post Doctoral student, Dr Neoh Chin Hong for their guidance and support throughout the journey in completing my research. I would also like to convey my heart-felt gratitude to team from IWK Konsortium Sdn Bhd Skudai. I truly appreciate the warm and condusive working environment in the Pollution Control Laboratory at Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia.To friends and colleagues, I would like thank them for their help, support and precious words of encouragement throughout the course of this research. I am also forever indebted to my family for their unconditional love, encouragement and tremendous support which helped me to get through this challenging phase of my life.

Last but not least, I would like to express my appreciation to Universiti Teknologi Malaysia and Ministry of Higher Education for their financial and generous support in funding this research under Fundamental Research Grant Scheme (FRGS).

ABSTRACT

Domestic wastewaters contain various and high amounts of organic matter and ammonia or nitrogen compounds which are difficult to oxidize biologically or chemically. A promising technology in treating wastewater which is membrane bioreactor (MBR) has been considered to be an advancement over the conventional activated sludge process. However, this type of MBR has a limitation which is membrane fouling problem that can reduce the perfomance of the system. Thus, in this study, advanced treatment technology in treating synthetic domestic wastewater called Hybrid Attached Growth Membrane Bioreactor (HyAG MBR) is proposed to help minimize and overcome the problem. The aim of this study is to find the optimum concentration of attached growth media that will be used in HyAG MBR system and compare the treatment and fouling tendency performance of conventional MBR (CMBR) with HyAG MBR. Synthetic domestic wastewater was treated with a 20 L lab-scale HyAG MBR equipped with a single microfiltration flat sheet membrane module. Batch tests with attached growth media concentrations from 10 to 40% were used to determine the best attached growth media concentration. Besides that, the treatment performances of HyAG MBR system were also compared with the performances of conventional MBR (CMBR) system by assessing the removal of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorus, nitrate, nitrite and ammonia concentrations. Furthermore, fouling tendency was also compared between HyAG MBR and CMBR systems at the same operating condition by evaluating critical flux (J_c) enhancement, trans membrane pressure (TMP) profiles, membrane resistance analysis, soluble microbial products (SMP) and extracellular polymeric substances (EPS). The finding shows 10% of attached growth media was an optimum concentration for good removal of COD, nitrate, nitrite and phosphorus up to 93.29 %, 94.53%, 90.04% and 61.86%, respectively. The average COD, nitrate, nitrite, nitrogen ammonia, phosphorus and BOD removal of HyAG MBR were 96.82%,96.54% , 92.91%, 93.30% , 75.55%, and 89.70% while for CMBR were 96.10%, 83.60%, 80.21% , 85.68%, 77.74% and 91.49%, respectively. Average COD, nitrate, nitrite, and nitrogen ammonia removal efficiency for HyAG MBR were found to be greater than the CMBR system but vice versa for phosphorus and BOD removal. HyAG MBR significantly increased J_c up to 48 L m^{-2} h^{-1} hence producing low final TMP after cleaning. Low TMP also decreased the total resistance at 5.69 x 10^{11} m^{-1} and have distinct changes in the concentrations of SMP and EPS. Thus, it shows the reduction of membrane fouling problem hence prolonging the filtration process. In conclusion, HyAG MBR gives a better treatment performance and could minimize the membrane fouling problem.

ABSTRAK

Air buangan domestik mengandungi kandungan bahan organik dan ammonia atau sebatian nitrogen yang tinggi serta sukar untuk dioksidakan secara biologi atau secara kimia. Teknologi berpotensi dalam merawat air sisa yang dinamakan bioreaktor membran (MBR) telah dianggap sebagai satu inovasi ke atas proses konvensional enapcemar teraktif. Walau bagaimanapun, MBR mempunyai masalah iaitu kotoran membran yang boleh mengurangkan prestasi sistem. Oleh itu, dalam kajian ini, teknologi rawatan terbaru dalam merawat air sisa domestik sintetik yang dikenali Bioreaktor Membran Pertumbuhan Melekat Hibrid (HyAG MBR) dicadangkan untuk membantu mengurangkan dan mengatasi masalah ini. Tujuan kajian ini adalah untuk mencari kepekatan optimum media yang akan digunakan dalam sistem HyAG MBR dan membandingkan rawatan dan prestasi kecenderungan kotoran membran konvensional MBR (CMBR) dengan HyAG MBR. Air sisa domestik sintetik telah dirawat dengan 20 L reaktor skala makmal HyAG MBR yang dilengkapi dengan satu modul membran kepingan rata penurasan mikro tunggal. Satu ujian secara berkelompok dengan kepekatan media 10-40% telah dilaksanakan untuk menentukan kepekatan media yang terbaik. Selain itu, prestasi rawatan sistem HyAG MBR juga dibandingkan dengan prestasi sistem MBR konvensional (CMBR) dengan menilai penyingkiran permintaan oksigen kimia (COD), permintaan oksigen biokimia (BOD), jumlah kepekatan fosforus, nitrat, nitrit dan ammonia. Selanjutnya, kecenderungan kotoran juga telah dibandingkan di antara sistem HyAG MBR dan CMBR pada keadaan operasi yang sama dengan menilai peningkatan kritikal fluks (Jc), profil tekanan trans membran (TMP), analisis rintangan membran, produk mikrob terlarut (SMP) dan bahan-bahan polimer luar sel (EPS). Dapatan analisis menunjukkan 10% daripada media merupakan kepekatan optimum yang baik untuk penyingkiran COD, nitrat, nitrit dan fosforus masing-masing sebanyak 93.29%, 94.53%, 90.04% dan 61.86%. Purata COD, nitrat, nitrit, ammonia nitrogen, fosforus dan penyingkiran BOD HyAG MBR adalah masing-masing 96.82%, 96.54%, 92.91%, 93.30%, 75.55% dan 89.70% manakala bagi CMBR adalah 96.10%, 83.60%, 80.21%, 85.68%, 77.74% dan 91.49%. Purata COD, nitrat, kecekapan penyingkiran nitrit, dan ammonia nitrogen untuk HyAG MBR didapati lebih besar berbanding sistem CMBR namun penyingkiran fosforus dan BOD bagi HyAG MBR pula lebih rendah berbanding sistem CMBR. HyAG MBR dengan ketaranya meningkatkan Jc sehingga 48 $Lm^{-2}h^{-1}$, oleh itu menghasilkan TMP akhir yang rendah selepas pembersihan. TMP yang rendah juga telah menurunkan jumlah rintangan pada 5.69×10^{11} m^{-1} dan menyebabkan perubahan yang berbeza dalam kepekatan SMP dan EPS. Jadi, ini membuktikan masalah kotoran membran telah berkurang seterusnya menghasilkan proses penapisan yang lama. Sebagai kesimpulan, HyAG MBR memberikan rawatan yang baik dan juga mampu mengurangkan masalah kotoran membran.

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LIST OF ABBREVIATIONS

μ	-	Viscosity
μm	-	Micrometre
ABS		Acrylonitrile butadiene styrene
AG-MBR	-	Attached growth MBR
BAP	-	Biomass associated products
Bf-MBRs		Biofilm Membrane Bioreactor
BOD	-	Biological Oxygen Demand
CAS	-	Conventional activated sludge
CMBR	-	Conventional Membrane Bioreactor
COD	-	Chemical Oxygen Demand
DO	-	Dissolve oxygen
EPS	-	Extracellular Polymeric Substances
F/M	-	Food per microbe
g/L	-	Gram per litre
GAC	-	Granular activated carbon
H_2SO_4	-	Sulphuric Acid
HMBR	-	Hybrid membrane bioreactor
HRT	-	Hydraulic retention time
Hy-SAG-MBR	-	Hybrid suspended attached growth MBR
IWK	-	Indah Water Konsortium
J	-	Permeate Flux
Jc	-	Critical Flux
kPa	-	KiloPascal
LMH	-	Litre per metre square hour
MB-MBR	-	Moving bed membrane bioreactor

MBR	-	Membrane Bioreactor
M-CMBBR	-	Membrane coupled moving bed biofilm reactor
MFI	-	Membrane fouling index
mg/g	-	Milligram per gram
mg/L	-	Miligram per litre
MLSS	-	Mixed Liquor Suspended Solids
MLVSS	-	Mixed Liquor Volatile Suspended Solids
NO_3-N	-	Nitrate Nitrogen
OLR	-	Organic loading rate
PAOs	-	Phosphorus-accumulating organisms
PE	-	Polyethylene
PhAC	-	Pharmaceutically active compounds
PO_4-P	-	Phosphate Phisphorus
PVDF	-	Polyvinylidene fluoride
Q	-	Flowrate
RBC	-	Rotating biological contactor
Rc	-	Cake Resistance
Rm	-	Intrinsic membrane resistance
Rp	-	Pore blocking resistance
Rt	-	Total Resistance
SBR	-	Sequential Batch Reactor
SEM	-	Scanning electron microscope
SMP	-	Soluble Microbial Product
SND	-	Simultaneous nitrification and denitrification
SOUR	-	Specific Oxygen Uptake Rate
SRT	-	Solid retention time
TMP	-	Transmembrane Pressure
TN	-	Total Nitrogen
TN	-	Total nitrogen
TSS	-	Total suspended solids
UAP	-	Utilization associated products
V	-	Volume
VOC	-	Volatile organic compund

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, increasingly stringent enviromental legislation and treatment technologies that are effective in removing wide range of pollutants, cost efficient and reliable are needed. Throughout the world, one of the most common methods that is flexible with reliable process and able to produce high quality effluent is conventional activated sludge process. Conventional activated sludge process is common biological process involving microorganisms which are grown in a variety of bioreactors while degrading particulates and dissolved wastes using suspended biomass. However, remaining problems of this process is poor settling of activated sludge biomass resulting to poor quality of effluent, decrease system capacity, and increase capital and operating costs. Besides that, this system also uses clarifying tank during sedimentation that obviously requires a large space and employs low volumetric loading rate. Thus, due to stringent effluent permits and the needs of population growth, an upgraded and expanding activated sludge system is required in order to treat wastewater in the future.

At present, there has been increasing interest in the use of attached growth systems which use support media for biomass growth. Usually, attached growth process is designed to minimize the limitation of suspended growth process. Based on previous studies , advantages of attached growth system are it is able to maintain high concentration of active biomass, able to maintain high biomass age, lower sensitivity to toxic effects, upgrades existing systems at minimum cost and also reduces sludge-settling period (Delatolla *et al*., 2008, 2009). Different attached growth systems have been used such as rotating biological contactor (RBC), trickling filter, fixed media submerged biofilter, fluidized bed reactors and others. For RBC, it is one of the biofilm systems that is effective, has low cost wastewater treatment because of short hydraulic retention time, excellent shock and toxic loading capability, simple process control and low energy requirement (Alemzadeh *et al*., 2001).

On the other hand, an upgraded wastewater treatment technology system called MBR has been selected as a suitable and effective way for wastewater treatment system. MBR is a system that combines activated sludge system and membrane filtration. In MBR system, sedimentation process is replaced with the filtration by membrane. Biological unit in activated sludge system plays a role for the biodegradation of the waste compounds while membrane module is responsible for physical separation of the treated water from the mixed liquor (Hoinkis *et al*.,2012). Biological process in MBR converts dissolved organic matter into suspended biomass, reducing membrane fouling and allowing increase in recovery (Friha *et al*., 2014). MBR is applicable in treating various types of domestic and industrial wastewater.

In previous studies, submerged MBR treating abattoir wastewater was run in 115 days resulting in stable removal efficiencies of organic and pathogens with a little excess sludge production (Keskes *et al*., 2012). The results show that this technology is a good potential in wastewater treatment. Besides, treatment of textile wastewater has also been done using aerobic MBR which also resulted in high average removal COD at 97% which is quite high (Badani *et al*.,2005). MBR is also successful in treating cosmetic industrial wastewater where it showed very good biodegrability after six months of continuous treatment, where the adopted aerobic bacteria was able to completely degrade a wide range of terpens, olefins, fatty acids esters and more particularly surfactants after 180 days of MBR operation (Friha *et al*.,2014).

MBR system is also applicable in attached growth process as an alternative and unique way to produce high effluent quality. The treatment performance of conventional MBR could be increased by the use of media in hybrid MBR due to high biomass concentrations and reduction of membrane fouling (Leiknes and Odegaard.,2007). For instance, attached microbial systems can lower membrane fouling by providing a surface besides membrane for microbial attachment, or by providing a location for soluble microbial products or hydrophobic compounds to adsorb, thus limiting sorption to the membrane and allowing increased time for degradation (Achilli *et al*., 2011). Additionally, Sombatsompop *et al* (2006) observed that formation of cake in suspended reactor is higher compared to attached growth reactor for all MLSS concentrations. Hence, it is noted that particle fouling in the attached growth reactor was lower than in the suspended reactor. This is due to the movement of attached media in the reactor which is responsible in producing small particles of biomass.

Hence, by integrating these two types of MBR systems, an upgraded and expanded MBR known as hybrid attached growth membrane bioreactor (HyAG MBR) can be developed in order to treat various types of wastewater. This system may also significantly reduce fouling tendency of MBR system as a major challenge. Therefore, the findings of this proposed study may also be helpful towards establishment of fundamental process mechanism of membrane filtration in the operation of a HyAG MBR treating high strength industrial or domestic wastewater.

1.2 Problem Statement

Due to more stringent regulations concerning various types of wastewater with several wide range of pollutants, advanced treatment technologies for a more efficient treatment of these effluents are required. As the country is rapidly developed, the increasing population of people will generate high amount of domestic wastewater. The effluent might consist of several types of pollutants that is possible to be untreated. This would give an effect to water quality of the river since the effluent of domestic wastewater will flow to the river causing water pollution. This situation affects the aquatic life and ecosystem problem. Sewage water pollution is actually one of the major problems especially in developing countries. Careless disposal of sewage waters may lead to some problems such as spreading of diseases, eutrophication, increase in Biological Oxygen Demand (BOD) and others.

Domestic wastewaters (DWW) contain varied and high amounts of organic matter which are difficult to oxidize biologically or chemically (Daghrir *et al.*, 2014). High strength DWW discharges in certain areas may cause an alarming increase in groundwater nitrate levels. Not many of the treated plants are designed to remove nitrogen from sewage and the effluent is normally utilised for surface irrigation (Gupta *et al.,* 2001). Besides, DWW is also one of the main sources for wastewater contaminations by ammonia or nitrogen compounds (El-Bourawi *et al*., 2007). As ammonia may cause the eutrophication and reduce the dissolved oxygen in water, the discharge of domestic sewage and industry wastewater with ammonia would lead to the death of aquatic life (El-Bourawi *et al.*, 2007, Tan *et al*., 2006). Thus, the removal of ammonia has become a major concern in wastewater treatment. Discharge of insufficiently treated DWW effluent to aquatic receptors, via direct discharge or base flow, may lead to excess nutrient enrichment, algal blooms and eutrophication (Withers *et al*., 2011). It can also lead to waterborne disease; numerous significant outbreaks have been attributed to DWW treatment system effluent ingress to drinking water sources (Naughton *et al*., 2014). Due to these challenges, it is crucial to find a wastewater treatment technology that can treat the wastewater efficiently. In order to deal with the problem of nutrient removal, more and more attentions were paid to membrane bioreactor process (MBR) (Kimura *et al*., 2008, Hao *et al*., 2016, Ersu *et al.*, 2010) which has become a promising technology for upgrading wastewater treatment over the past few decades.

A promising technology in treating wastewater which is MBR has been considered to be an advancement over the conventional activated sludge process. However, this type of MBR has a limitation which is membrane fouling problem that can reduce the perfomance of treated wastewater . Nguyen *et al*. (2012) also stated that conventional activated sludge-based MBRs pose operational and R&D problems such as membrane fouling, high energy consumption, and limited nutrient removal capability. Membrane fouling reduces the membrane life, requires more energy for backwashing and makes the system less efficient. Membrane fouling results in performance reduction, severe flux decline or rapid pressure increase and frequent membrane cleaning, thus directly leading to an increase of operating and maintenance costs (Wang *et al*., 2016). Therefore, reducing membrane fouling is one of the top priorities in enhancing MBR performance.

Fortunately, attached growth MBR has been found to solve membrane fouling problem and could also prolong filtration due to the difference in particle size distribution of biomass between these two reactors. Biofilm MBR (BF-MBR) or attached growth MBR is the addition of carriers inside the MBR that reduces the concentration of suspended solids and leads to mitigation of membrane fouling. This system is able to reduce the concentration of suspended solids without limiting the efficiency of the process (Leyva-Díaz *et al*., 2013). It offers several advantages such as higher biomass activity and higher resistance to toxic substances (Igor Ivanovic., 2011). Subtil *et al*. (2014) also reported that BF-MBR showed better removal in ammonia and TN as well as lowered the fouling rate about 35% compared to MBR.

Even though some of the wastewater treatment system may be able to treat industrial wastewater to meet current disposal requirement and producing water for basic uses in the industry, the treated effluent would need to be further polished by using integrated MBR for applications that need high grade water (Neoh *et al.*, 2016). The purposes of the integrated MBR are to improve qualities of permeates, mitigate membrane fouling and enhance the stability of the treatment process. In this study, membrane and attached growth media were inserted in one reactor. Thus, due to the limitation of different types of both MBR, advance treatment technology in treating industrial or domestic wastewater combining both type of MBR called HyAG MBR is proposed.

1.3 Objectives of the Study

This study embarks on the following objectives:

i. To determine the optimum concentration of attached media in the HyAG MBR system for treating domestic wastewater treatment on a batch system.
ii. To compare fouling tendency of conventional MBR with HyAG MBR system at the same operating conditions.
iii. To compare treatment performance of conventional MBR with HyAG MBR system.

1.4 Scope of the Study

The scope of this study is as follows:

i) The 20L lab-scale HyAG MBR using single flat-sheet Kubota MF was setup to treat DWW. This set-up was completed with attached growth media, pressure gauge, peristaltic pump, water level meter, air flowmeter, air pump, air diffuser, pH meter, and pressure data logger

ii) The synthetic DWW was used to get less fluctuation in nutrient values. Synthetic DWW of about 1000 mg L^{-1} of COD were fed to the HyAG MBR.

iii) Batch reactor test was conducted in order to find the optimum concentration of attached growth media that will be used in HySAG MBR system. The attached growth reactor was added with four different concentrations of media of 10%, 20%, 30% and 40%. The experiment was run for 20 days and samples were collected twice a day and analyzed in terms of COD,nitrate, nitrite and phosphorus removal. The optimum concentration of attached growth media was utilized for the next stage of experiment.

iv) Several analytical methods were applied to evaluate the treatment performance between conventional MBR and HySAG MBR. These included measurement of COD removal, BOD, total phosphorus, nitrate, nitrite and Ammonia concentrations.

v) Since membrane fouling became a major problem in MBR, TMP profiles, critical flux analysis and membrane resistance analysis was conducted to analyze membrane fouling characteristics. The analysis of MLSS/MLVSS, EPS and SMP analysis was also evaluated to test the membrane fouling tendency.

1.5 Significance of Study

The findings of this proposed study may significantly help towards establishment of a fundamental process mechanism of membrane filtration in the operation of a HyAG MBR treating high strength industrial or domestic wastewater. Moreover, this study helps towards finding better wastewater treatment technology in order to achieve requirement of more stringent regulations of wastewater effluent today. This analysis may also enhance the capacity of wastewater treatment engineers or researchers that focus on MBR technology to understand the key variables that affect MBR performance, allowing them to avoid situations that cause poor performances. As mentioned, membrane fouling is a major challenges in MBR systems. Thus, this design of MBR system could help towards overcoming fouling problem. HySAG-MBR might also help in overcoming fouling problem which is a major challenge in MBR.

1.6 Chapter Outline

The literature review of this research discussed in Chapter 2. This chapter explained the domestic wastewater, application of membrane bioreactor in wastewater treatment, advantages and disadvantages of MBR and also the types of MBR used in wastewater treatment. Besides that, this chapter also includes membrane fouling topic that was discussed briefly in section 2.3. Moreover, Chapter 3 is focusing on experimental procedure and also experimental analysis of this study. Last but not least, results and discussion of this research discussed in Chapter 4. Then, Chapter 5 is the conclusion of the results from the experiment. Achievement of the objectives discussed in the conlusion part. The process of research includes problem solving, suitability of the methods and possibility of future research was summarized in this chapter.

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